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Patent analysis of the course of aerojet's business and the key technologies of hypersonic

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Abstract

This study researched the patents published from 1942 to March of 2014 of Aerojet Company (including Aerojet Rocketdyne Company's patents) in USA, considering Aerojet's annals and other information, analyzed relationship of the patents and the course of Aerojet's business development, and the technology R&D process, and extracted the key hypersonic technologies of Aerojet Company, at last raised the conclusion.

Peer-review under responsibility of Chinese Society of Aeronautics and Astronautics (CSAA)

Keywords: Aerojet; Hypersonic; Patent analysis; Core Burning; Integrated Inlet; Aerodynamic Choke

1. Introduction

Aerojet Company established in 1942 by Dr. Theodore von Karman, which is a traditional American arms company. Its main business is design, manufacturing and production of solid, liquid rocket engine. It has been involved in the Gemini Project, Apollo Project and other American important aerospace projects. 2013, Aerojet's parent GenCorp spent $550 million to purchase Aerojet's industry rival Pratt&Whitney's Rocketdyne to established the Aerojet Rocketdyne Company. Aerojet Rocketdyne Company which has two main rocket suppliers of the United States upgraded the strength and position in the area of the engine to achieve a qualitative leap.

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From Aerojet to Aerojet Rocketdyne, Aerojet has focused on engine development and production more than 70 years, to accumulate a strong patents resources and advanced core technology in the field to become the world's leading engine manufacturers.

In recent years, Aerojet had great achievements in the field of hypersonic, and raised "T/RBCC", "Core Burning" and other new technologies, and in cooperation with Lockheed Martin Skunk Works, launched the engine research of SR-72 hypersonic unmanned aircraft.

This study researched the patents published from 1942 to March of 2014 of Aerojet Company (including Aerojet Rocketdyne Company's patents) in USA, considering Aerojet's annals and other information, analyzed relationship of the patents and the course of Aerojet's business development, and the technology R&D process, and extracted the key hypersonic technologies of Aerojet, at last raised the conclusion.

2. Aerojet's Business Development Process Analysis

Since Aerojet Company was founded about 70 years ago, it had produced more than 2,000 patents. Its patent publishing trend showed in Figure 1[†]. Patent Publication trends shows Aerojet experienced five stages, including growth stage, the rapid growth stage, the business expansion stage, the recession stage and the revival stage.

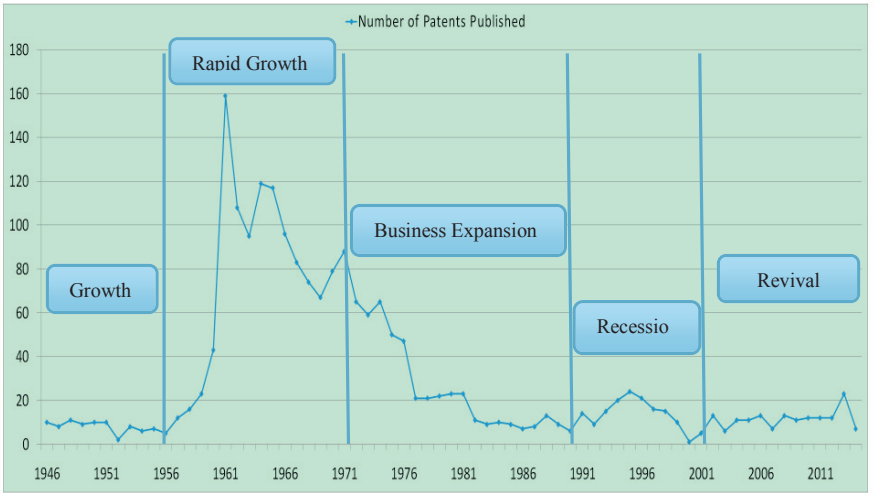

Fig. 1. Aerojet's patents publishing trends from 1946 to March of 2014

2.1. Growth stage

Because of the Aerojet's JATO technology[‡] is widely used in World War II, since it founded, the company has entered a growth period, with the number of patent applications every year higher. GenCorp predicted that the company's strong growth prospects of Aerojet, acquired it in 1948. In order to enhance innovation capability, Aerojet also absorb some of the scientists of the German V-2 rocket program who surrender America. The early 1950s, Aerojet began manufacturing intercontinental ballistic missiles, propulsion systems guided missiles and submarine-launched surface to air missiles. Its innovation capabilities continue to burst, and gradually expand the size of the company.

[†] Patent search time ended March 31, 2014, using Thomson Reuters TI platform.

[‡] The new technology of making larger loading aircraft took off from short runways or short decks of carrier.

2.2. Rapid growth stage

The late 1950s to the early 1970s, Aerojet patent applications began to show explosive growth, with the annual patent applications approaching 160. Space Race brings several groundbreaking government investment projects for Aerojet, including the development of Titan rocket propulsion systems, Gemini manned spacecraft, Viking Mars Lander and other major projects. At the same time, Aerojet took a lot of ordnance production tasks in Vietnam War, effectively promoted Aerojet's technology innovation. Aerojet's technical innovation has brought fruitful results. In 1969, Aerojet's rocket engine made American astronauts gone to the moon successfully.

2.3. Business expansion stage

In the late 1970s, Aerojet launched diversified investment company, under which there are 14 companies in the operations, and business areas including energy, chemicals, construction, parts production, food flavoring agent and so on. However, Aerojet's patent applications didn't climb with the expansion of business scale, but declined. This may be due to the company's focus more on high-level investment rather than technology development. GenCorp which is Aerojet's parent company gradually recognized this problem. Early 1980s, GenCorp stripped part of the Aerojet subsidiary, prompting Aerojet focused on the aviation business. In 1988, the company's sales reached $1 billion. The earlier stage rapid expansion of the company also planted the bad seeds for Aerojet. Due to carry out a large number of chemical business, the company involved in environmental litigation undertaken by the government ordered cleanup of groundwater contamination. According to estimates by the United States General Accounting Office, the cost could be as high 1 billion, the company has brought tremendous pressure on the operation, which may also reduce the amount of patent applications as a factor.

2.4. Recession stage

Since the beginning of the 1990s, Aerojet entered a "decade of recession". First reason was the environmental problems involved before caused loss, and second, because the majority of the year the U.S. government's defense budget experienced negative growth, the third is in 1993 the U.S. Congress canceled the space shuttle solid-fuel rocket engine provided by Aerojet and Lockheed Martin's plans. 1990s, a few years ago, the Aerojet patent applications reduced. After the company launched twice massive layoffs and the sale of part of the business, the amount of patent applications increased.

2.5. Revival stage

After 2000, in order to further enhance the strength of the engine field, Aerojet conducted three large-scale mergers and acquisitions and business integration. Once for Redmond-based Space Propulsion and Fire Suppression, the second time is to promote business for Atlantic Research Corporation (ARC) of space, and the third is due to the company's merger with Rocketdyne. Above adjustments of Aerojet prompted the company completed the advance capability portfolio in the field of satellite and tactical missile systems. The company began to restore vitality again, the number of patent applications began to rise.

3. Aerojet's technical research and development process analysis

Aerojet Company focused on the rocket engine field more than 70 years, R&D focus areas continues to be adjusted with the change of external market environment.

We retrieved and read Aerojet's patents and discovered, from the 1960s to the 1990s, Aerojet's patents heavily concentrated in engine related technologies, fine chemicals, fire extinguishing equipment and Alloy several major areas, which engine-related patents accounts for 30%. The phenomenon is consistent with the company's business at the actual time and situation of Aerojet. 1990s, Aerojet also launched a patent portfolio in the medical field, such as tourniquets and so on.

After 2000, though the amount of annual patent applications wasn't big, but clearly Aerojet focused on engine-related technologies, and the technical field of patent distribution more refined, including the combustion chamber and nozzle technology, intake technology, the engine cooling technology and ignition technology, which reflects Aerojet's strategy after making adjustments. The business landscape is gradually transformed from the diversification to strengthen the engine area of research to some extent. The R&D capabilities of the engine area of Aerojet are more powerful. This is because in the 1990s, Aerojet company sold its fine chemicals business, stop the research and production, focused research and development efforts to engage for strategic, tactical missile research solid, liquid aspirated engines and engines , and partly because the military demand for engine technology increasing.

4. Aerojet's hypersonic core technology analysis

By screening 2055 Aerojet's patents, combined with the number of patent families, we get Aerojet's hypersonic core technology which is mainly T/RBCC engine technology, specifically includes: Core Burning technology, Advanced Combined Cycle Integrated Inlet technology and Aerodynamic Choke technology.

4.1. Coring Burning technology

From the patents, we find Aerojet's core inventor Melvin J. Bulman applied two patents, which are US2008/0092519A1 (patent Publication Number) and US7797943B2 (patent number), elaborated on the work principle, specific programs and advanced of the Coring Burning technology.

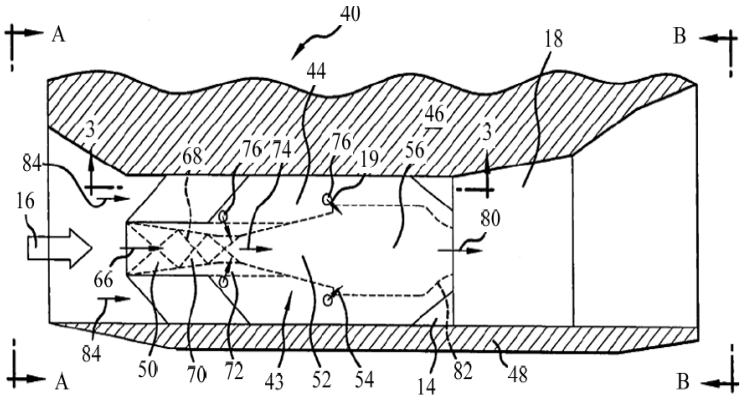

Fig. 2. Center scramjet combustion structure

14- main isolator; 16- to flow; 18- main combustion chamber; 19- fuel; 40- scramjet; 43- guide; 44- strut; 50- guide isolator; 52- guide diffuser; 54- guide flameholder; 56- guided combustion chamber; 66- direct airflow; 68- shock train; 70- supersonic core flow; 72- subsonic boundary layer; 76- guide nozzle; 80- guide hot exhaust ; 82- guide nozzle; 84- mainstream

As shown above, in Aerojet's patent, scramjet constituted with inlet, isolator, combustor and nozzle began front to back. The innovation of this technique is that the guide is provided in axial symmetry of the isolator. Guide includes a guide isolator, guide diffuser, flame stabilizer, guide combustion chamber and nozzle guide. Export-led isolator inlet is in communication with the engine, and export import guided combustion chamber is in communication with the main combustion chamber of the engine. The outer surface of the center guide connected with the inner wall of isolator by more than one strut.

Coring Burning technology is designed to solve problems that on hypersonic flight conditions, longstanding limit the combustion chamber heat load. It can significantly reduce the amount of fuel to cool the engine, so that the

engine is designed to obtain greater thermal safety margin than conventional or higher speed. T/RBCC engine combustion technology through the use of the Coring Burning will enable the engine heat load reduction of 40% to 50%; through the use of rocket ejector ramjet, can achieve hypersonic vehicle seamless transition from Mach 0 to Mach 7. Due to these advantages, the technology has become one of the power scheme reusable hypersonic vehicles of the most attractive and promising.

4.2. Advanced Combined Cycle Integrated Inlet technology (ACCII)

Currently, the technical difficulties of combined cycle engine which must overcome include: the low thrust at transonic, low Mach number inlet start, yet no turbine engines which can accelerate to Mach 4 or more, transition zone thrust trough, heat balance while cruising, and no suitable full-size combination circulating free jet-flow engine's ground test equipment.

Aerojet's inlet integrated combined cycle technical solution adopted is the opening to the booster in a position remote from channel centerline, so that its turn inward flow path inlet has a higher integration and performance of the nozzle, in order to achieve inlet deformation. In order to increase the flow to match the needs and the distribution of air, in the contraction deformation of the inlet must be able to obtain excellent acceleration performance.

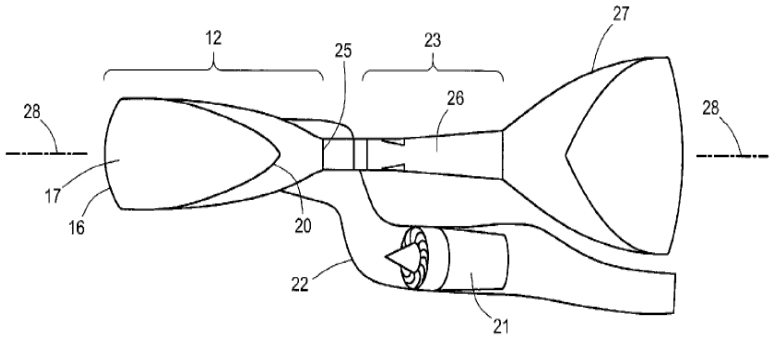

Fig. 3. Advanced combined cycle integrated inlet structure

12- imports; 16-channel; 17- upper lip mouth; 20- flow downstream end; 21- boost engine; 22- channel; 23- ramjet; 25- throat; 26- combustion chamber; 27- distributaries' area ; 28- vertical axis;

As one of the main inventor of Aerojet, Melvin J. Bulman in its publication number US7216474 patent, describes works and advanced of this advanced combined cycle integrated inlet technology (ACCII). As shown above, the innovation of this technology is that you can move through the inlet inside the body to adjust the portfolio engine inlet air flow, thus avoiding the engine or engine airflow to capture parts of the deformation, so that the activities can be avoided the leading edge is exposed to the air, to ensure efficient working of the engine and to minimize the results of the shock wave.

4.3. Aerodynamic Choke technology

From patent analysis, we find that Aerodynamic Choke technology is a major innovative of TBCC engine program in Aerojet's hypersonic field. Its working principle is to use the under expanded exhaust in turbine engine, to form Aerodynamic Choke at the back of DMRJ (Dual Mode Ramjet, dual-mode ramjet), to come into being a new combustion zone. The advantage is improving DMRJ thrust at low Mach number while maintaining the inlet started.

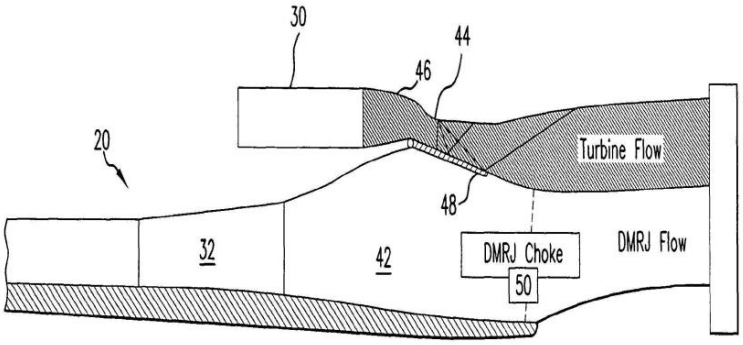

Fig. 4. The formation of Aerodynamic Choke

20- engine; 30- turbine engine; 32- chamber; 42- engine nozzle; 44- boost engine; 46- airflow; 48- nozzle cover; 50- Aerodynamic Choke

To achieve Aerodynamic Choke, there are two main techniques, one is reasonable arrangements for turbine engine exhaust port and the relative position of DMRJ, the second is the rational design of the nozzle cover, which can effectively regulate integration into the turbine engine exhaust nozzle to form an Aerodynamic Choke. Special attention is needed, which the cross section is greater than the cross section of the integrated nozzle DMRJ combustor.

To enhance DMRJ combustion chamber area ratio, thereby increasing DMRJ thrust, we also can use other complex variable nozzle technology, but the above method of Aerojet taken under the same circumstances nozzle geometry to achieve a change in the area of the internal combustion, regarded as a relatively easy way for hypersonic aircraft engine engineering application. It's a good reference.

5. Conclusion

5.1. Aerojet's development process is closely related to the external political and military environment, and has strong dependence on government programs

We can initially see from the patents the history of the rise and fall of development of Aerojet Company: the company's establishment and growth is closely related to external political and military factor, like government investment projects, the Vietnam War, and its decline is also closely related to government investment revoked or reduced. Although late Aerojet made strategic adjustments, but its R&D focus is still placed on the aircraft engine business which government investment projects closely related. Meanwhile, in order to reduce business risk, to prevent the "recession" appeared again, Aerojet also made a reasonable choice of the military development of secondary industry, spawned by-products in the field of medical and other applications.

5.2. Aerojet developed both weapons propulsion and space propulsion business

Aerojet is propulsion technology-based company. Its business gradually expanded into the field of space by the missile field, coming into the current form of weapons and space propulsion parallel development pattern. Due to the strategic position of the two areas and technical similarities, Aerojet is easier to concentrate superior R&D and production of advanced products in the business development process.

5.3. According to the changes of external environment for timely acquisitions or division ,is an important strategy of adjustment of the Aerojet

According to external environment changes in the political, military, legal, etc., Aerojet uses the way of acquisitions and division, with their own advantages and development, timely adjusts the company's business structure and operations. For example, the timely release of adverse business, acquired with a large R&D Raymond-related businesses. Such conduct is good for the ability to effectively integrate resources, enhance the strength, and achieve the strategic realignment of the company.

5.4. Mastered the core technology of the engine business is becoming the focus of Aerojet development

After a long period of recession, Aerojet comes to realize the blind expansion of early stage may give company a devastating disaster. Diversified business development must be with the development of core technology, otherwise unsustainable. Therefore, mastering core technologies of engine business becomes the focus of Aerojet's development.

5.5. Aerojet's core technology of hypersonic vehicles may have a certain realization of the project

Aerojet's Core Burning technology, Advanced Combined Cycle Integrated Inlet technology and Aerodynamic Choke technology are useful attempt to enhance engine performance of hypersonic vehicles. More technical clever technical ideas and techniques, such as the use of nozzle cover to form Aerodynamic Choke can be combined or applied separately to the relevant research. Because of these techniques is improving the existing research base, the basis of the technology of turbine engine and ramjet engine is more mature. It's easy to implement re-use, can effectively reduce costs, and achieve good results, so it has a better realization of the project.

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